

Laboratory Investigation of Grouted Coupler Connection Details for ABC Bridge Projects



**Final Report
August 2015**



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16. Abstract <p>With an ever increasing desire to utilize accelerated bridge construction (ABC) techniques, it is becoming critical that bridge designers and contractors have confidence in typical details. The Keg Creek Bridge on US 6 in Iowa was a recent ABC example that utilized connection details that had been utilized elsewhere.</p> <p>The connection details used between the drilled shaft and pier column and between the pier column and the pier cap were details needing evaluation. These connection details utilized grouted couplers that have been tested by others with mixed results—some indicating quality performance and others indicating questionable performance. There was a need to test these couplers to gain an understanding of their performance in likely Iowa details and to understand how their performance might be impacted by different construction processes.</p> <p>The objective of the work was to perform laboratory testing and evaluation of the grouted coupler connection details utilized on precast concrete elements for the Keg Creek Bridge. The Bridge Engineering Center (BEC), with the assistance of the Iowa Department of Transportation (DOT) Office of Bridges and Structures, developed specimens representative of the Keg Creek Bridge connections for testing under static and fatigue loads in the structures laboratory. The specimens were also evaluated for their ability to resist the intrusion of water and chlorides. Evaluation of their performance was made through comparisons with design assumptions and previous research, as well as the physical performance of the coupled connections.</p>					
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INTRODUCTION

Background

The use of prefabricated structural elements has become an integral part of many accelerated bridge construction (ABC) efforts. For many years, the ABC methodology has steadily gained popularity among transportation officials as an effective means of reducing construction duration and impacts on traffic. Other benefits of ABC include improving work zone safety, minimizing temporary roadway construction, minimizing post-construction repairs to detour routes, and reducing user/societal costs.

With more widespread use of ABC by bridge engineering communities, it is critical that bridge designers and contractors have confidence in details typically encountered in ABC designs. However, many ABC projects involve connection details that are either unfamiliar to the bridge engineer/contractor, are untested, or potentially both.

Previous laboratory testing of specific ABC connection details has shown that not all connection details function in the ABC bridge application as they are sometimes promoted by their developers. Therefore, it is important that connection details be evaluated in the form in which they are or will be utilized in the ABC process to assess their integrity and performance.

In the recent past, ABC has brought about new construction technologies, methodologies, and connection details. Many of these techniques and details have been designed specifically for the ABC application while others have been borrowed from other construction applications and at times slightly modified to meet the demands and needs of the ABC project(s). These borrowed technologies and methodologies are often morphed into an ABC project on a schedule that preempts any physical testing to validate their structural adequacy in that application.

Empirical and theoretical justification are often completed, although some of the data providing the basis of that justification are from manufacturer-based testing that may or may not directly pertain to the ABC application. One such technology is the grouted reinforcing steel coupler.

Grouted reinforcing steel couplers have received considerable attention because they allow a quick and relatively easy means to connect precast concrete elements. Bridge engineers and contractors now recognize the benefits of using grouted reinforcing steel couplers to accelerate the speed of construction, increase productivity, and simplify design details. However, they are untested in these specific applications and, for designers and contractors to confidently design and build ABC bridges using grouted reinforcing steel coupler connections that are sustainable, durable, and low-maintenance, the coupled connections must be tested and evaluated in these ABC specific applications.

Problem Statement

With an ever increasing desire to utilize ABC techniques, it is becoming critical that bridge designers and contractors have confidence in typical details. The Keg Creek Bridge on US 6 was a recent ABC example that utilized connection details that had been utilized elsewhere. The connection details used between the drilled shaft and pier column and between the pier column and the pier cap were details needing evaluation.

These connection details utilized grouted couplers that have been tested by others with mixed results—some indicating quality performance some indicating questionable performance. There is a need to test these couplers to gain an understanding of their performance in likely Iowa details and to understand how their performance might be impacted by different construction processes.

Research Objective and Overview

The objective of the work was to perform laboratory testing and evaluation of the grouted coupler connection details utilized on precast concrete elements for the Keg Creek Bridge. The Bridge Engineering Center (BEC) at Iowa State University, with the assistance of the Iowa Department of Transportation (DOT) Office of Bridges and Structures, developed specimens representative of the Keg Creek Bridge connections for testing under static and fatigue loads in the Iowa State University Structural Engineering Laboratory.

Specimens were also evaluated for their ability to resist the intrusion of water and chlorides because chloride penetration resistance is an important criterion for coupled connections on bridges, especially in areas below expansion joints at the abutments and piers such as on the Keg Creek Bridge.

Performance evaluations were made through comparisons with design assumptions and previous research (which typically only evaluated coupler strength in a pure tension test), as well as the physical performance of the coupled connections.

Research Approach

This study included a literature review that focused on the state-of-the practice related to testing and evaluation of the performance of grouted reinforcing steel couplers, laboratory evaluation of several prefabricated bridge specimens connected with grouted reinforcing steel couplers designed to simulate the connection utilized for the Keg Creek Bridge project, and evaluation of individual coupled connections subjected to moisture and chlorides.

The researchers conducted a series of laboratory tests of an ABC connection utilizing sleeve-lock grouted reinforcing steel couplers to evaluate the grouted coupler connection details. Laboratory testing involved static and fatigue testing of full-scale precast elements coupled together and loaded in four-point bending to simulate the loading typical to the drilled shaft to pier column

connection utilized in the Keg Creek Bridge. In addition, several small-scale specimens were cast, each including one grouted reinforcing steel coupler for submersion in a chloride solution to evaluate the resistance of the connection to penetration of moisture and chlorides.

LITERATURE REVIEW

A search was conducted to locate literature relevant to the testing and use of grouted reinforcing steel couplers. The Federal Highway Administration (FHWA) has reported an increased use of grouted reinforcing steel splice couplers, as well as other types of reinforcing steel couplers, in recent years (Culmo 2011).

Details and recommendations pertaining to the use of these types of couplers in connections of prefabricated bridge elements and systems are outlined in another FHWA Highways for LIFE report related to ABC construction (Culmo 2009). Culmo reports that these three main grouted coupler products are in use in the US: NMB Splice Sleeve, Erico Lenton Interlok Rebar Splicing System, and Dayton Superior DB Grout Sleeve.

The Dayton Superior DB Grout Sleeve uses non-shrink grout to fill a steel casting to splice reinforcing together. This product is typically used for both cast-in-place and precast concrete construction (DSC Evaluation Service 2011). The manufacturer performed testing on its product and subsequently produced an evaluation report (DSC Evaluation Service 2011).

This report details the proper grouting method for the couplers, the testing procedure used, and test results. The testing consisted of pure tension tests only, with each coupler cast in concrete. Eight bar sizes were tested and, for each size, eight specimens were tested. The ultimate force, specified yield, and failure mode were tabulated.

The Michigan Department of Transportation (MDOT) evaluated the NMB Splice Sleeve and Lenton Interlok (Jansson 2008). MDOT tested each product for slip, fatigue, ultimate load, and creep. Each splice was tested in tension. The goal of these tests was to determine if these products were suitable for connecting elements of a precast concrete structure.

Both product specimens displayed little displacement under a 1,000,000 cycle fatigue test. In all of the tests, the splices were able to exceed at least 125 percent of the bar's yield strength. During the sustained loading tests, MDOT found that neither splice is vulnerable to significant displacement caused by creep. The only negative findings were that the epoxy coating may contribute to a reduction in the ultimate load capacity after sustained loading. During these tests, it was assumed that axial tension tests would give a conservative prediction of the splice's behavior when in service. As a result, these splices were never tested for flexural strength.

In 2009, a series of tests were performed on mechanical couplers by the Army Corps of Engineers (Rowell et al. 2009). Several types of couplers were tested including grouted couplers. A dynamic loader was used to apply concentrated loads on each specimen and strain gauges were used to monitor each specimen's response to axial loading.

During this literature search, the research team found there is insufficient research on grouted coupler systems. There have been only a handful of tests, and all of these tests neglected the importance of flexural strength and the interaction of flexural and other loads.

There are several examples of successful implementation of grout sleeves, such as the Keg Creek Bridge project, where the Iowa DOT used Dayton Superior DB Grout Sleeves to accelerate the construction of the bridge drastically. Additional research into the performance of grouted reinforcing steel couplers with details typical to bridge construction are warranted.

LABORATORY SPECIMEN EVALUATION

Key aspects facilitating the accelerated construction of the Keg Creek Bridge in less than two weeks were the connection of the drilled shafts to the prefabricated concrete pier columns and the connection of the pier columns to the prefabricated pier caps. Both of these connections utilized grouted reinforcing steel couplers from Dayton Superior.

As this was the first project utilizing these couplers in ABC connections on an Iowa DOT project, questions arose regarding the strength and durability of the coupled connections in this application. These questions were in large part the result of the fact that, as noted previously, most of the testing conducted on grouted reinforcing steel couplers to date had been pull-out tests, most with no concrete surrounding the coupled reinforcing steel connection.

Design

Several critical factors were considered during the design of the specimens for the laboratory testing to ensure the tests results would be representative of the performance of the coupled connections on the Keg Creek Bridge.

First, the couplers needed to be the same size and brand as those used on the Keg Creek Bridge; this meant #14 epoxy-coated grouted reinforcing steel couplers from Dayton Superior would be used for laboratory testing. Use of such large reinforcing steel and reinforcing steel couplers led to the use of full-scale specimens to the extent possible within the limitations of the project budget and testing facilities.

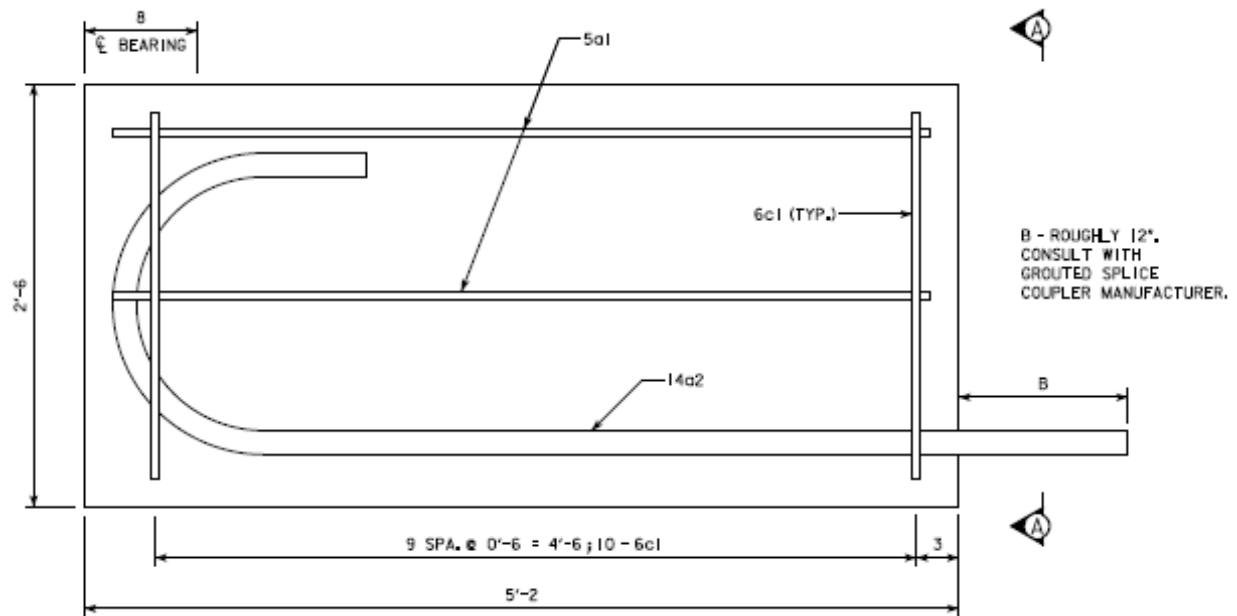
Second, loading of the laboratory specimen must be representative of the field loading of the coupled connections. Therefore, instead of a pure-axial tension type test, the coupled connection needed to be evaluated in a bending configuration and the specimen needed to be designed accordingly.

Third, erection of the coupled connection should be representative of the methods used on the Keg Creek Bridge to eliminate sources of ambiguity.

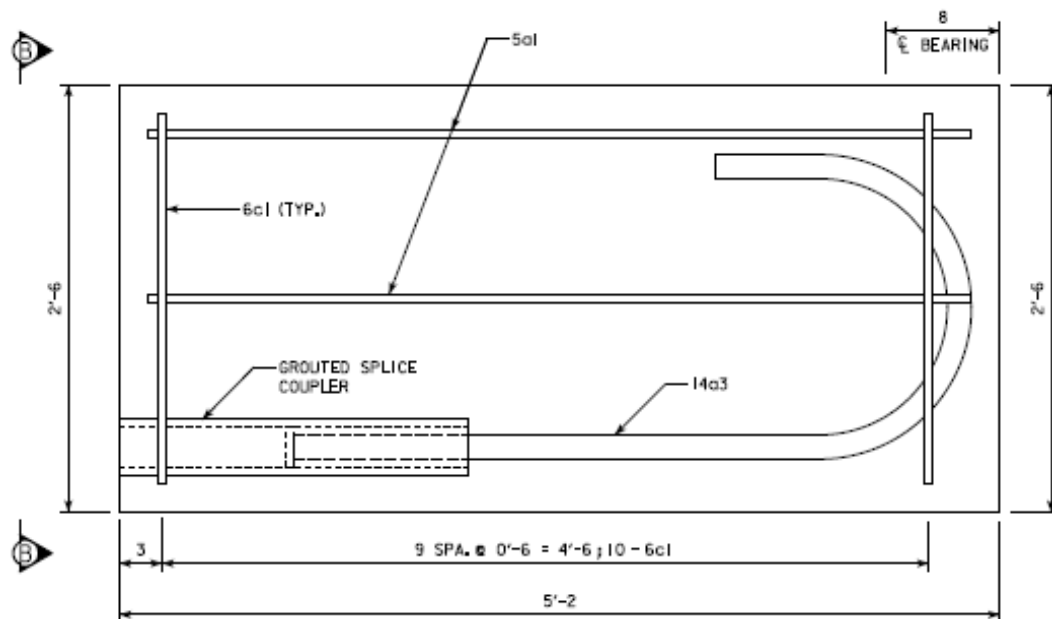
Finally, as alluded to previously, the specimens needed to be sized such that they could adequately be erected, fit, and tested in the confines of the structural testing facility.

Initial specimen design started by taking the #14 coupler and the height limitations of the testing facility into consideration since the specimen would need to be coupled vertically to mimic the vertically oriented connection at Keg Creek. To replicate this in the laboratory with the full-scale specimens, the top portion of the specimen (representing the pier column) would need to be lifted high enough to clear the #14 reinforcing steel protruding from the top of the bottom specimen (representing the drilled shaft) while fitting within the height limitations of the overhead crane. This limited the total height of the coupled specimen to approximately 10 to 12 ft, allowing space for the protruding bars and crane rigging.

At Keg Creek, the pier columns were square cross-sectionally, and since the specimen would be tested in four-point-bending, the decision was made to make the specimen rectangular cross-sectionally, with the couplers at the bottom of the coupled joint, i.e. in the tension zone. See Figures 1 and 2 for specimen cross-section and plan view schematics.



Side A



Side B

Figure 1. Grouted coupler specimen plan view

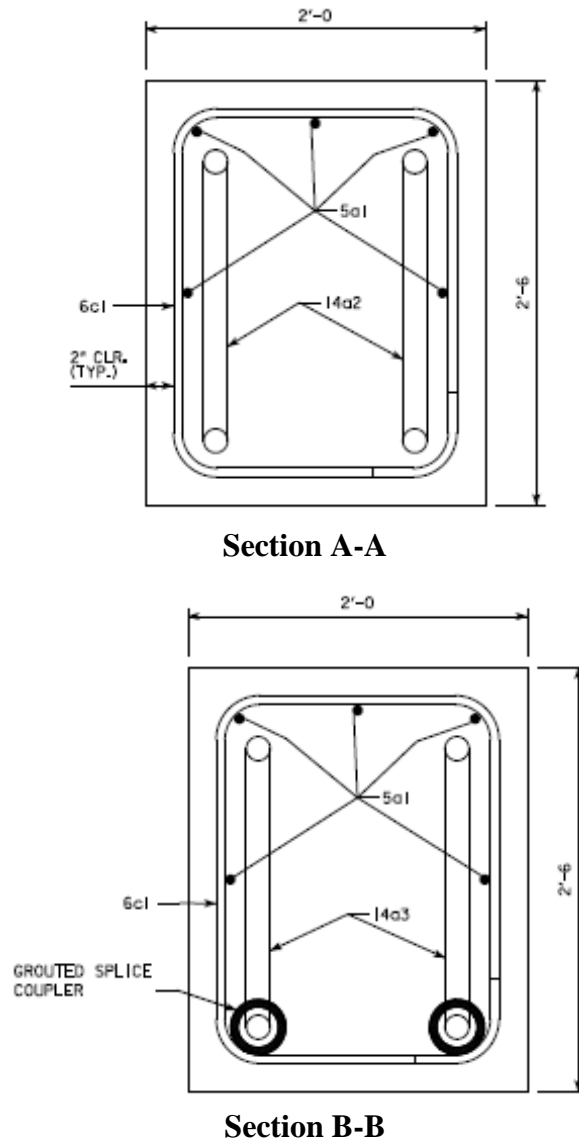


Figure 2. Grouted coupler specimen cross-section view

The specimen was ultimately designed based on developing the two #14 bars used as tension reinforcing in the bottom of the specimen. The two #14 bars, as tension reinforcement, do not meet American Association of State Highway and Transportation Officials (AASHTO) (2010) Load and Resistance Factor Design (LRFD) Specification 5.7.3.4. Control of Cracking by Distribution Reinforcement. However, since there is no additional crack control reinforcing steel in the connections utilizing the grouted couplers at Keg Creek, this was not considered to be critical to this study. Using a four-point bending loading setup, the calculated point load, P , on the specimen based on development of the two #14 bars was found to be $P=444$ k.

Fabrication

Figure 3 shows the formwork, reinforcing cage, and #14 bars and couplers for the laboratory specimens during construction.



Figure 3. Laboratory specimen reinforcement cage, couplers, and bars

The two sections of each specimen were cast horizontally so they could be match casted to facilitate easy coupling and ensure adequate consolidation of the concrete into the forms and around the bars and couplers.

Figure 4 shows the bottom portion of one specimen after removal of the forms and the protruding #14 bars.



Figure 4. Protruding #14 bars from Side A of the specimen

Figure 5 shows both portions of the specimen reoriented vertically, in a dry fit configuration, with the coupler grout ports visible.



Figure 5. Dry fit of Side B on top of Side A in laboratory

Seven specimens were cast for testing. For future reference, Table 1 lists the specifics for each of the seven specimens.

Table 1. Characteristics of the seven coupled specimen erected for testing

Specimen ID	Loading	Joint Prep	Joint Grout	Axial Load
Specimen 1	Static; L/2	Sand Blast	W. R. Meadows 588-10k	NA
Specimen 2	Static; L/3	Sand Blast	W. R. Meadows 588-10k	NA
Specimen 3	Static; L/3	Sand Blast	W. R. Meadows 588-10k	NA
Specimen 4	Static; L/3	Sand Blast	W. R. Meadows 588-10k	54k
Specimen 5	Static; L/3	Sand Blast	W. R. Meadows 588-10k	115k
Specimen 6	Static; L/3	Form Retarder	UHPC	54k
Specimen 7	Fatigue; L/3	Form Retarder	UHPC	NA

Specimens 1 through 3 utilized sandblasting on the grout bed surface and W. R. Meadows 588-10k grout, which was the grout used at Keg Creek, for the bedding grout with no axial load. Specimens 4 and 5 were then cast and erected using the same procedure and materials but with an applied axial load during static testing. Specimens 6 and 7 were cast last in the same manner, but used a form retarder, specifically Altus In-Form Retarder (pink) from Architectural Concrete Chemicals, on the interface to be grouted, and ultra-high performance concrete (UHPC) for the bedding grout. The objective of using the form retarder was to create a roughened exposed aggregate surface at the interface. Figure 6 shows the concrete interface after removing the forms with the form retarder.



Side A grout face



Side B grout face

Figure 6. Specimen grout bed interface using form retarder

Specimen 6 was used for static testing with an applied axial load and Specimen 7 was used for fatigue testing.

Erection and Grouting

Erection of the specimens began with installation of a dam around the top of the bottom specimen to contain the grout for the grout bed. Shims were installed to ensure a specific grout bed depth and to ensure that all of the grout was not pressed out of the joint (see Figure 7).

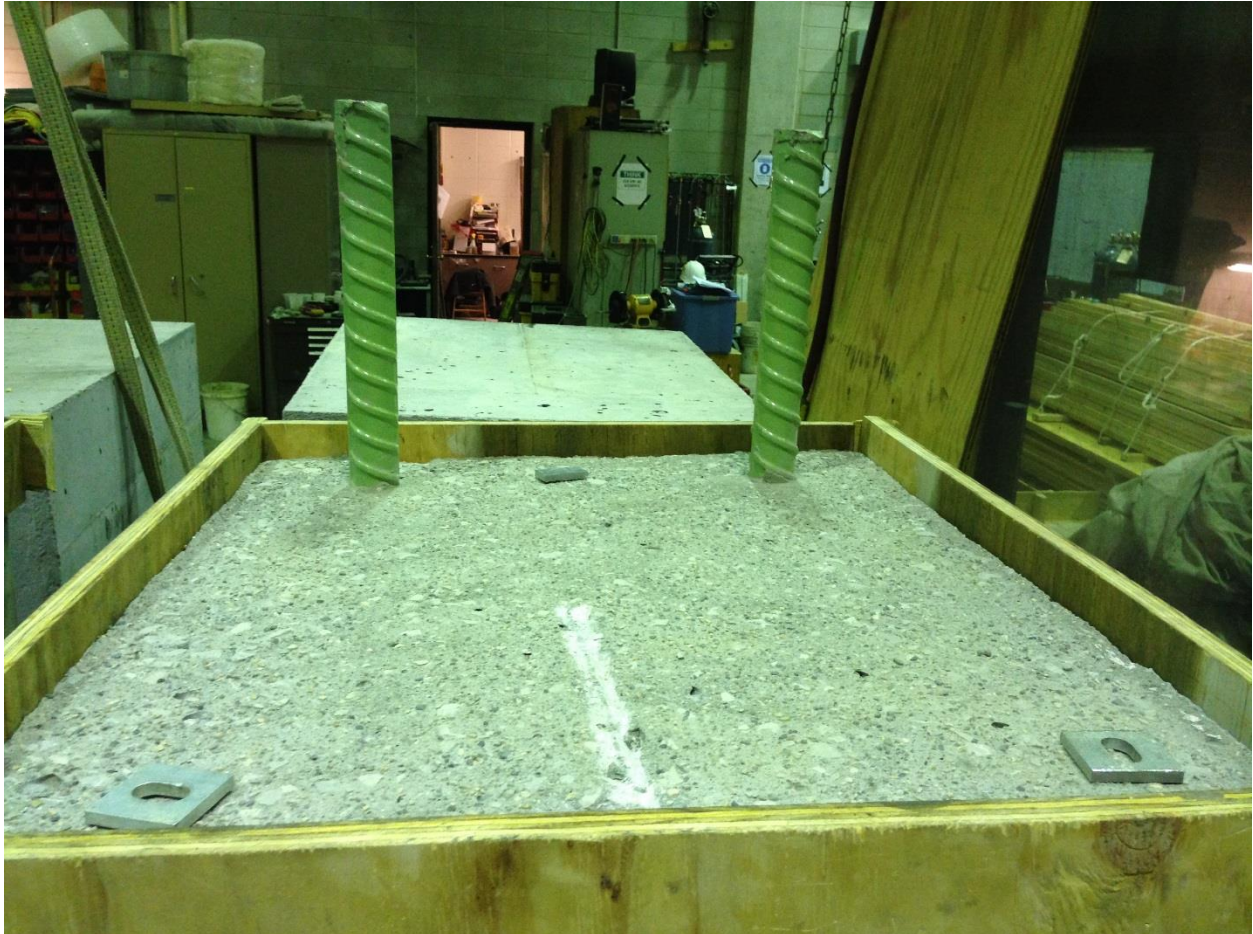


Figure 7. Dam around the top of the bottom specimen to contain the grout for the grout bed

Sleeve-lock seal plugs were used on the protruding reinforcing steel to prohibit bedding grout from entering the couplers. Once all three were properly in place, the grout was placed on the top of the bottom specimen and the top specimen was carefully lowered on top (see Figure 8).



Figure 8. W. R. Meadows grout bed (top) and UHPC grout bed (bottom)

Figures 9 and 10 show the completed grout beds for one specimen using W. R. Meadows 588-10k grout and another using UHPC as the grout bed, respectively.



Figure 9. Specimen grout bed using W. R. Meadows 588-10k



Figure 10. Specimen grout bed using UHPC

After installation of the bedding grout, the reinforcing steel couplers were grouted. The couplers were grouted using Dayton Superior Sleeve-Lock Grout and a hand pump (Figures 11 and 12).

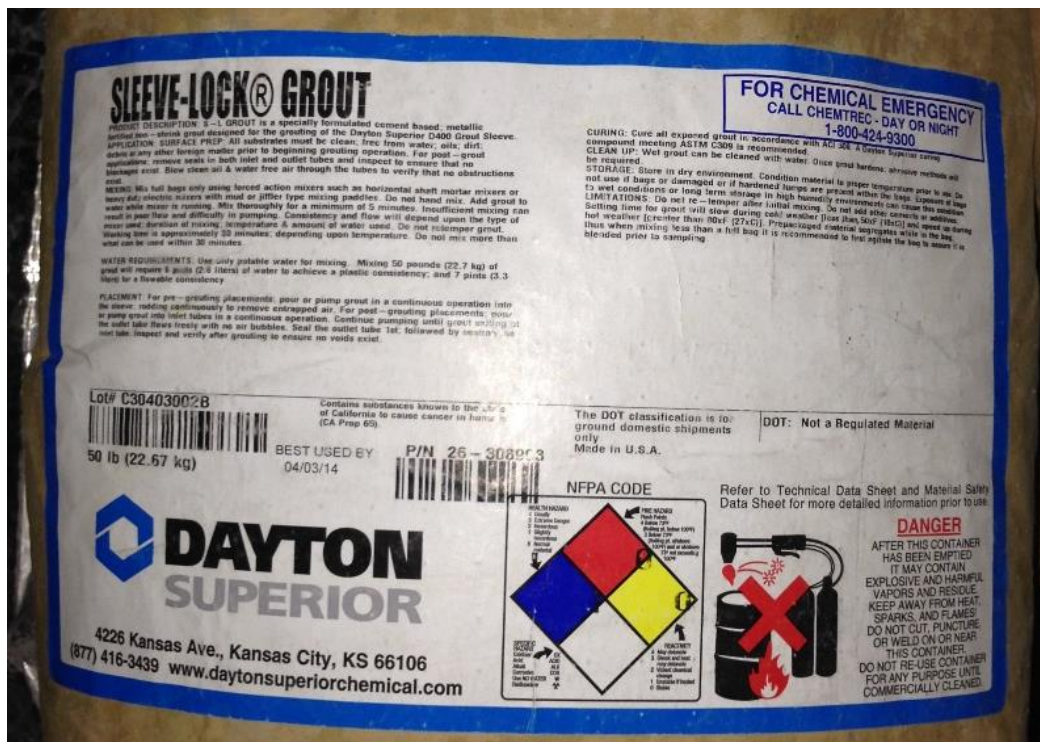


Figure 11. Dayton Superior Sleeve-Lock Grout label



Figure 12. Grout pump used for grouting the reinforcing steel couplers

Each batch of grout was mixed per manufacturer recommendations and pumping of the grout was completed as follows: 1) mix grout, 2) fill pump hopper with grout, 3) insert nozzle of pump into lower port of the grouted coupler, 4) slowly pump the grout into the coupler until it begins to come out of the top port of the coupler, 5) with a steady stream of grout exiting the top port, plug the top port using a port plug, 6) quickly remove the pump nozzle and plug the bottom port with a port plug. Figure 13 illustrates the ports before grouting and Figure 14 illustrates the ports after grouting with port plugs installed.



Figure 13. Port plugs before grouting



Figure 14. Port plugs installed after grouting

Grout cubes were cast for all batches of bedding grout and coupler grout for testing their 28-day compressive strength. The W. R. Meadows bedding grout achieved an average compressive strength of 8,960 psi, the Dayton sleeve-lock grout had an average compressive strength of 10,700 psi, and the UHPC mix achieved a compressive strength of 17,490 psi.

Testing Procedure

For the Keg Creek Bridge project, both of the connection details utilizing the grouted reinforcing steel couplers were in regions where their primary loading mechanism during service would be axial compression, mainly due to dead load, and bending due to both thermal effects and live loads from the superstructure. Two options were considered to replicate this loading mechanism in the laboratory: 1) keeping the specimens in their vertical orientation, attempting to anchor the base of the specimen to a nearly fixed-condition, and applying a horizontal load to the top of the specimen to create a bending moment at the coupled joint and 2) after coupling the specimens, reorient them to the horizontal position such that the grouted couplers are at the base of the specimen and subject them to four-point bending. The second option was selected because it allowed for the elimination of shear effects and application of greater loads and because it eliminated the complicated fixed connection detail required for the vertical testing scenario (among other reasons).

Following curing of the bedding and coupler grout and validation of their 28-day compressive strengths, the specimens were braced in their vertical orientation by anchoring steel angles and channels to the sides and tops of the specimens. The bracing reinforced the grouted joints as the specimens were carefully lowered to their horizontal positions for testing. Figure 15 shows one specimen in its vertical braced condition prior to lowering it.



Figure 15. Vertical braced specimen before lowering to horizontal position for testing

A cursory inspection of the grout joint was completed subsequent to the lowering of each specimen to ensure no cracking of the joints had occurred, and none was observed.

After lowering a specimen, and prior to removing the bracing, the specimens were individually moved into the load test frame and put on pin and roller supports. Once a specimen was in the proper loading position, the bracing was removed and the load actuator and spreader beam for the four-point bending setup were installed.

Figure 16 and 17 are schematics of the load setup with span dimensions and load placement.

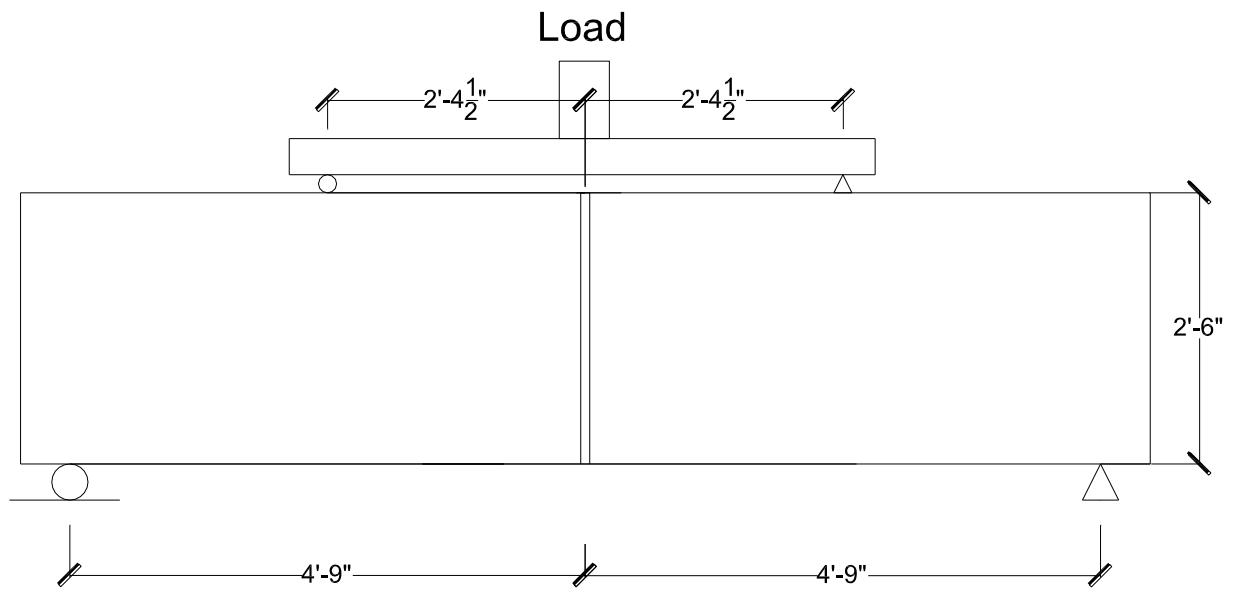


Figure 16. Four-point bending (L/2) setup for grouted coupler specimens

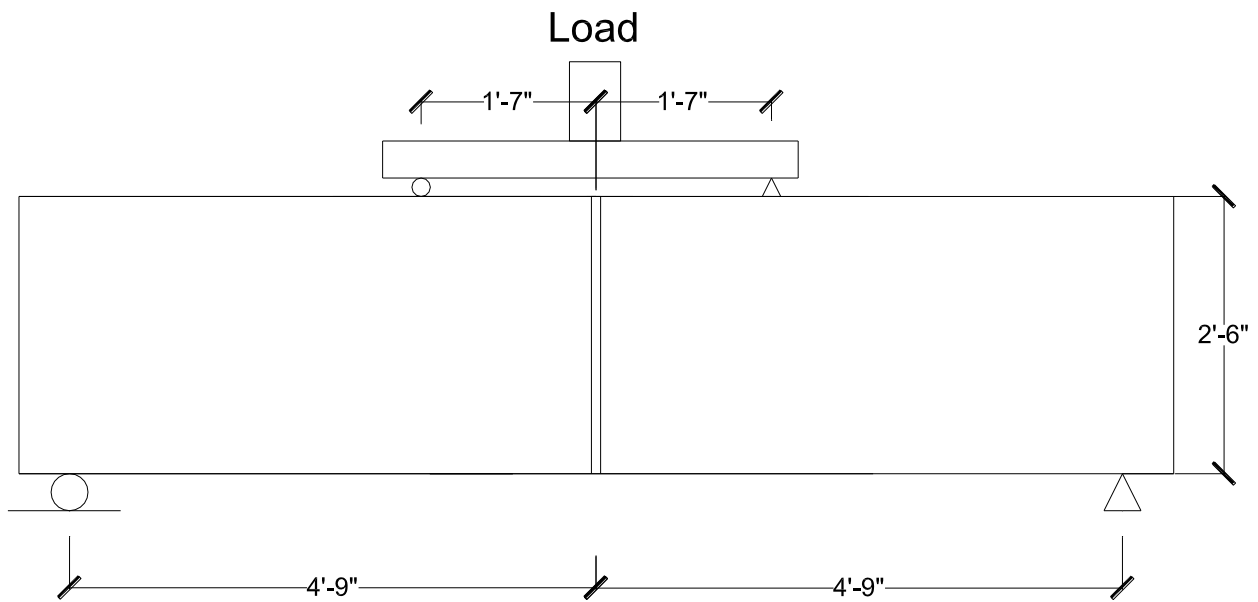


Figure 17. Four-point bending (L/3) setup for grouted coupler specimens

Figure 18 shows one specimen in the test frame ready for loading.



Figure 18. Specimen setup for static four-point bending test

Specimen 1 was loaded using span length divided by 2 ($L/2$) for the four-point bending setup. The load setup was adjusted to $L/3$ for the remainder of the testing to allow for a greater moment at the grout joint. Specimens 1 through 3 were loaded and tested as shown in Figure 18.

Following testing of the first three specimens, a discussion with the technical advisory committee (TAC) led to questions regarding whether an imposed axial load, such as would be found in the columns of the Keg Creek Bridge due to dead load, would affect the static behavior of the specimens and ultimately the cracking of the joint under bending load.

Subsequently, Specimens 4 and 5 with the W. R. Meadows grout beds were tested with an applied axial load (one with an axial load of 54k, and the other with an axial load of 115k). These two axial loads represent 75 psi and 160 psi on the joint, respectively, which were calculated to be the bounds of an equivalent pressure on the specimen scaled from the axial dead loads in the column at Keg Creek depending on whether the scaling was based on the number of couplers or on concrete area.

Figure 19 shows a specimen in the test frame setup with an axial load applied with post-tension rods.



Figure 19. Specimen setup for static four-point bending test with applied axial load

Instrumentation and Loading

Instrumentation of the specimens consisted of crackmeters placed across the grouted joint on the bottom of the specimen in line with each of the grouted couplers. In addition, a global deflection transducer was placed at midspan of each specimen to obtain load versus deflection information. Lastly, strain transducers from Bridge Diagnostics, Inc. (BDI) were installed on the sides of the specimens directly below the load points near the top and bottom edges, and on the underside of the specimen in line with the grouted couplers.

Figures 20 and 21 show the instrumentation placement for all of the specimens tested.

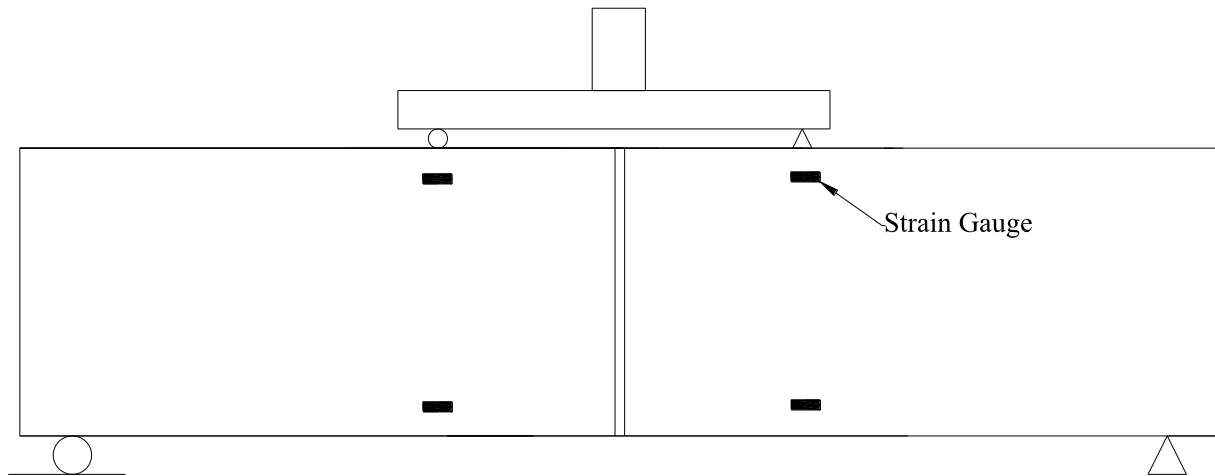


Figure 20. Instrumentation layout on the sides of each specimen

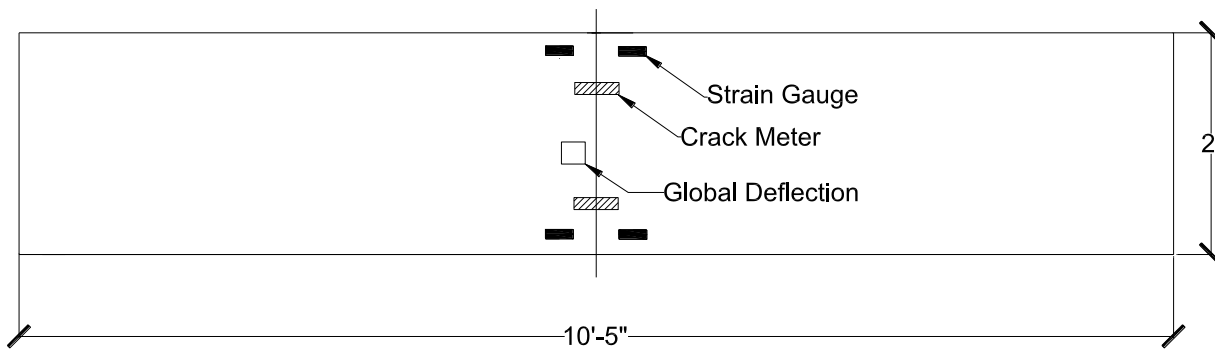


Figure 21. Instrumentation layout on the undersides of each specimen

Figure 22 shows the crackmeters and gauges near the joint on the underside of a specimen.



Figure 22. Crackmeters and strain transducers near the joint on the underside of a specimen

Each of the static specimens were loaded using a 400k hydraulic actuator and hand pump. Because the objective of the testing was to evaluate the performance and durability of the grouted joint under loading (i.e., cracking of the joint under load), there was no need to load the specimen to ultimate load/failure.

For fatigue testing, a 225k actuator was used in the four-point bending setup ($L/3$), as shown in Figure 23, along with a computer-driven hydraulic pump cycling the actuator at approximately 1 hz for 1 million cycles.



Figure 23. Coupler specimen setup for fatigue testing

The applied load for the fatigue test was calculated assuming the recommended 18ksi reinforcing steel stress from Table 5.5.3.4-1 from the AASHTO LRFD Design Specification (AASHTO 2010) for fatigue greater than or equal to 1 million cycles. Therefore, assuming the stress in the two coupled #14 reinforcing steels to be 18ksi, the applied load was calculated to be 106.3 kip, and 106 kip was used for testing.

In addition to the structural testing of the grouted joint, several small specimens were cast to evaluate the chloride penetration resistance of an un-cracked coupled joint. Figure 24 provides a cross-section view of the coupled specimens used for chloride penetration testing.

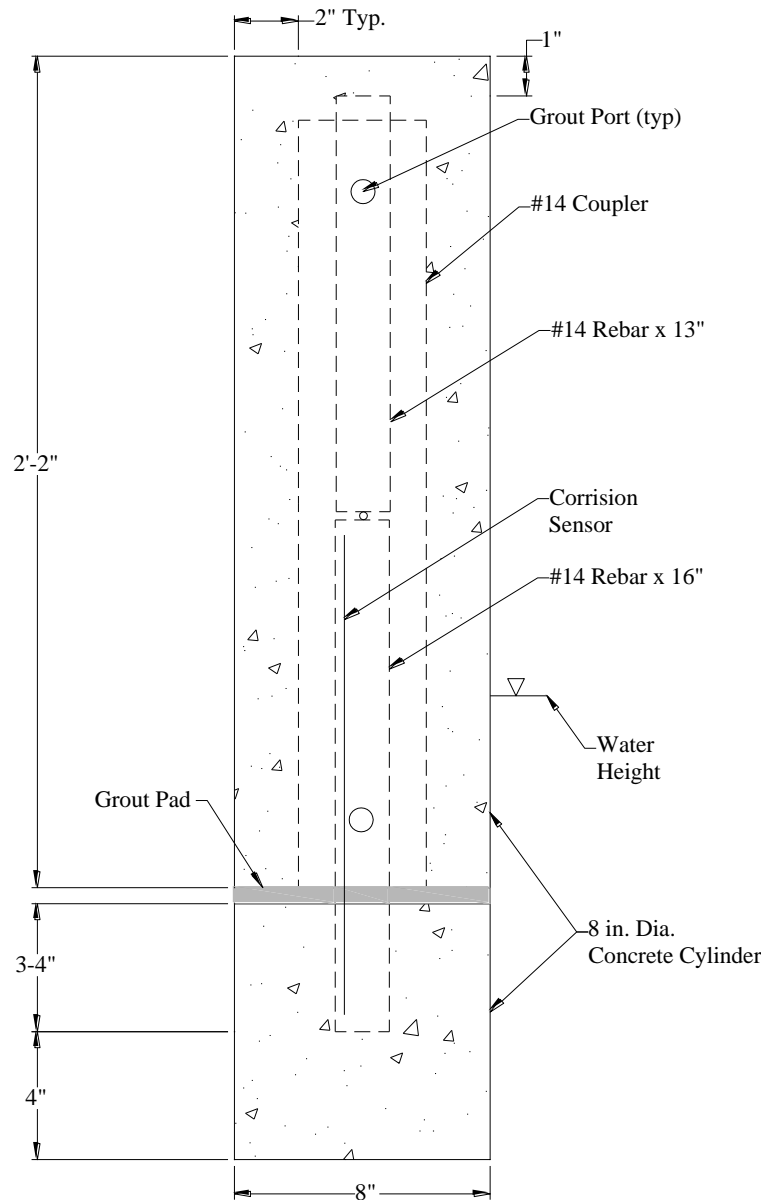


Figure 24. Cross-section view of coupler specimens for chloride penetration tests

All three specimens included a full-sized #14 grouted reinforcing steel coupler, just as were used in the large specimen, and the grout bed and grouting of the couplers was the same as that used on the first three large specimens and the Keg Creek Bridge. The grouted couplers were cast into an 8 in. diameter sonotube to provide a minimum of 2 in. of clear cover around the circumference of the coupler. Another 8 in. diameter cylinder with a protruding #14 bar was then grouted to the section with the coupler.

Figures 25 and 26 show specimens before and after grouting, respectively.



Figure 25. Small grouted coupler specimens prior to grouting



Figure 26. Small grouted coupler specimen after grouting

The reinforcing steel in these three specimens were outfitted with corrosion wire and submerged in a 3 percent chlorine bath to just above the grouted joint. The specimens were allowed to soak for approximately 6 months with periodic readings taken on the corrosion wire.

LABORATORY TEST RESULTS

Static Bending Results

Initial static testing of the grouted coupler specimens was completed on Specimens 1 through 3, with each loaded in four-point bending to approximately 360 kips. As previously mentioned, the load configuration for the first specimen was span length (L) divided by 2 ($L/2$), as shown in Figure 16. Figure 27 illustrates the moment versus crack width for Specimen 1, with the moment being the calculated moment at the joint.

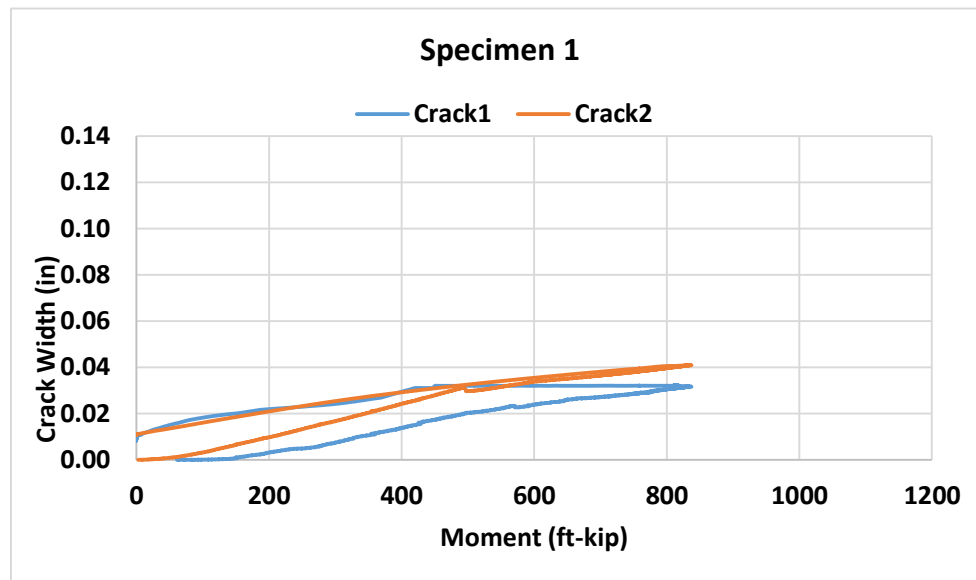


Figure 27. Moment versus crack width for Specimen 1

The crack width was measured by the two crackmeters, labeled Crack1 and Crack2, on the underside of the specimen.

After testing the first specimen, the research team decided to shift the four-point loading from $L/2$ to $L/3$ to increase the moment on the joint. This decision was made in attempt to widen the crack at the joint and evaluate if it closes after removal of the load. Subsequently, Specimens 2 and 3 were tested in this configuration and the results are shown in Figures 28 and 29, respectively.

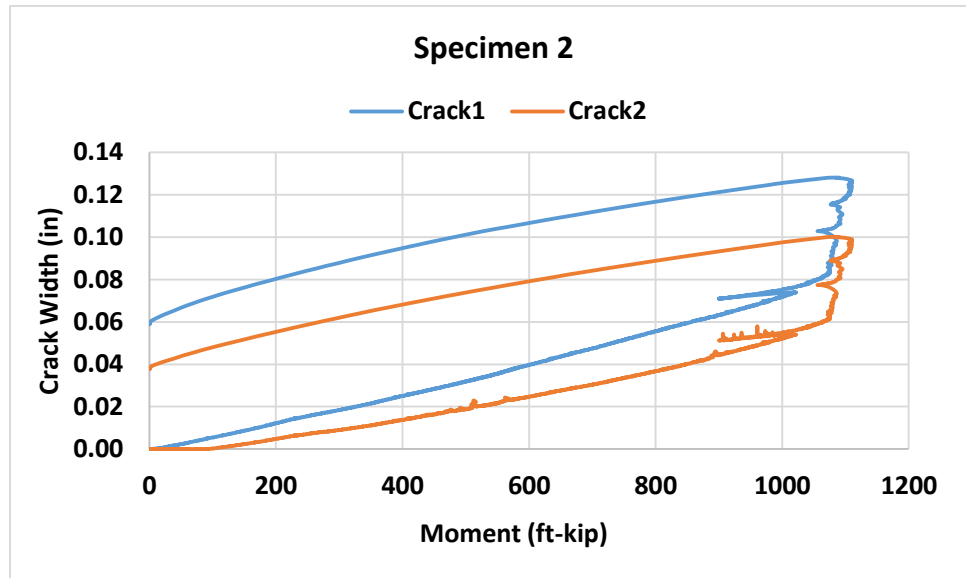


Figure 28. Moment versus crack width for Specimen 2

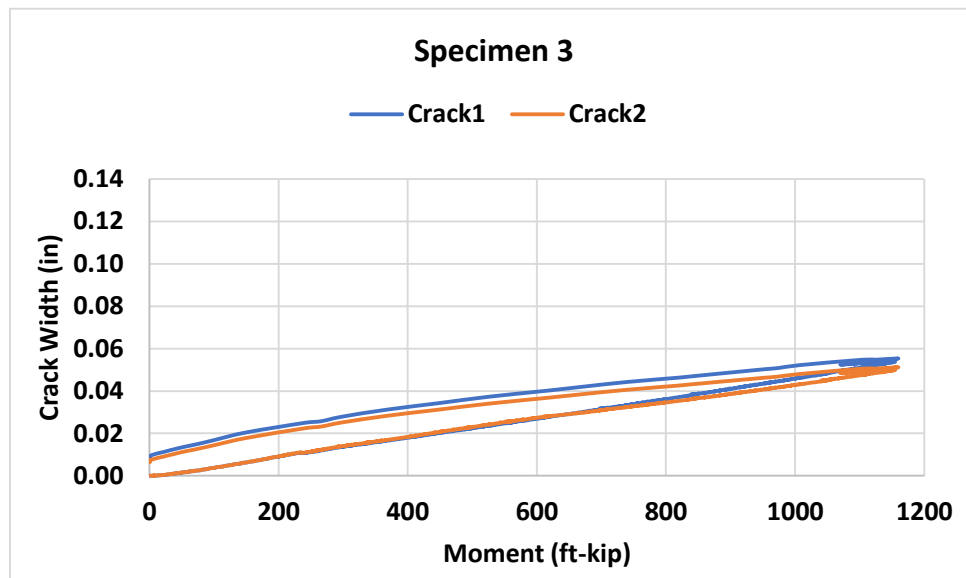


Figure 29. Moment versus crack width for Specimen 3

Specimen 1 and 3 both exhibited good closure of the crack after removal of the load. The Specimen 2 crack width did not close as much after unloading, although this is believed to be the result of the sustained peak load on this specimen. Peak load was temporarily maintained on

Specimen 2 for a longer period of time simply to allow for documentation of cracking and taking photographs. However, this type of loading may be more representative of the loading mechanism created by temperature affects in the field.

Following the testing of Specimens 1 through 3, Specimens 4 and 5 were instrumented and tested with an applied axial load to better represent the in-service connection detail at Keg Creek (Figure 19). Both of these specimen were loaded using the L/3 test configuration. Figures 30 and 31 show the moment versus crack width data for Specimen 4 (54k axial load) and Specimen 5 (115k axial load), respectively.

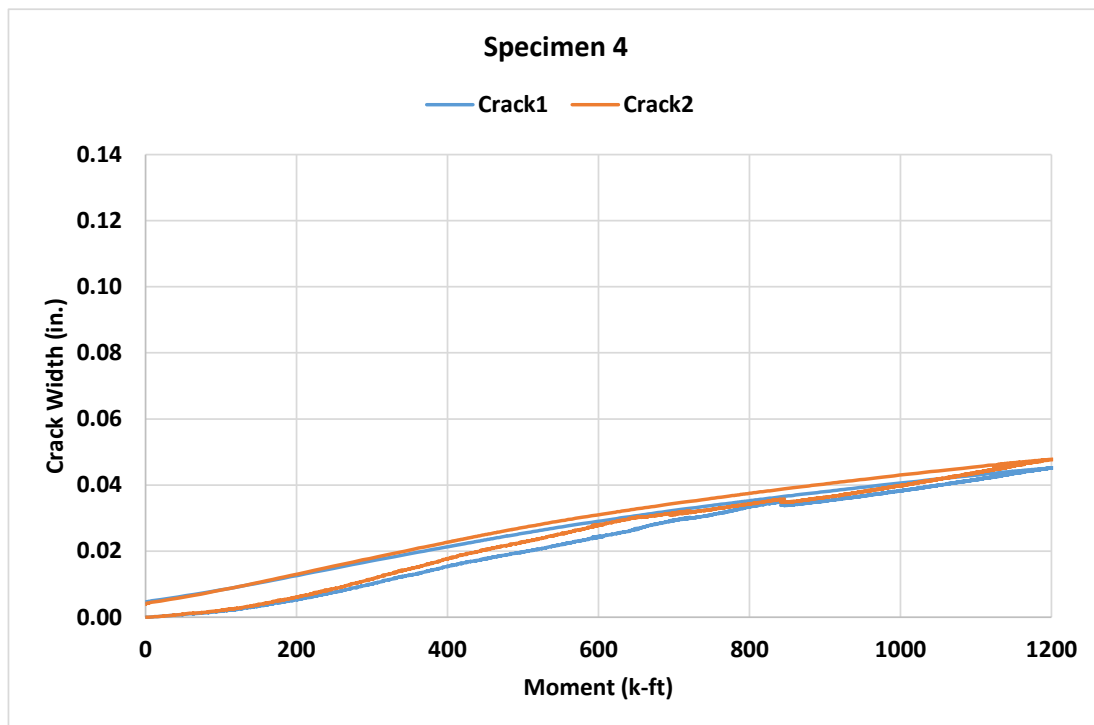


Figure 30. Moment versus crack width for Specimen 4

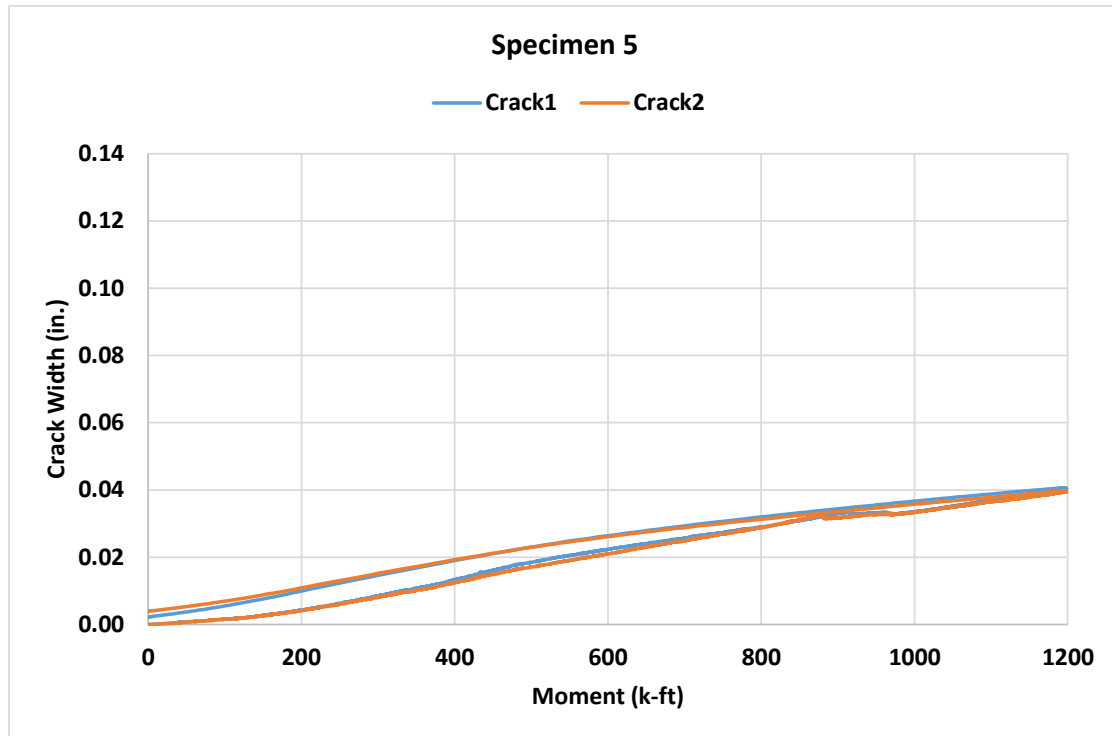


Figure 31. Moment versus crack width for Specimen 5

From Figures 30 and 31, it is evident that the axial loads applied to Specimen 4 and 5 only slightly decreased the crack width at the peak load when compared to Specimens 1 through 3, although there is an improvement of approximately 50 percent in the residual crack width once the load was removed.

For Specimens 1 through 5, cracking of the joint typically occurred on one of the interfaces between the existing concrete and the grout and started almost immediately after loading, as seen in Figures 32 and 33.

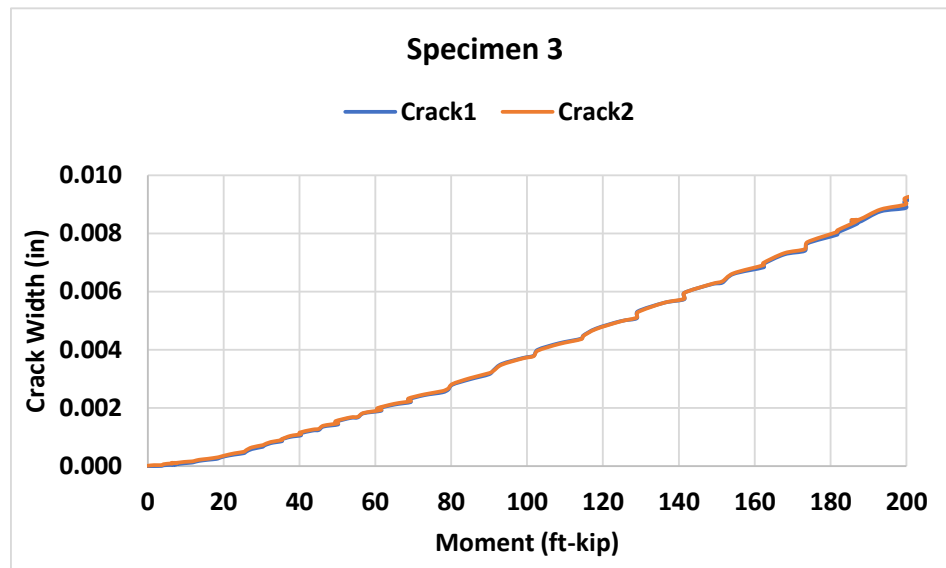


Figure 32. Typical initial crack width for specimen with no axial load, Specimen 3

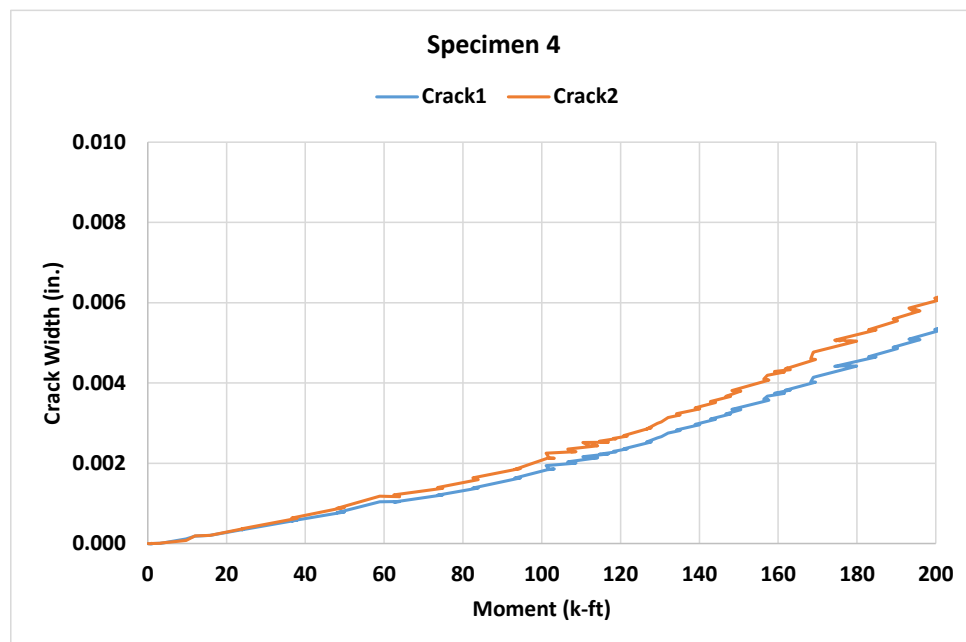


Figure 33. Typical initial crack width for specimen with axial load, Specimen 4

Essentially, the crack formed due to debonding of the grout.

Knowing this, the research team utilized one of the two remaining coupler specimens to evaluate if use of UHPC for the bedding grout material would improve the performance of the joint under

static loading. Specimen 6, consisting of a UHPC grout bed and an applied axial load of 54k, was statically tested following the same load setup (L/3) and instrumentation setup as the previous tests.

This setup of Specimen 6 allowed for a comparison of the data from Specimen 6 with data from Specimen 4 to evaluate the effect of the UHPC on the performance of the joint under loading. Note that one of the crackmeters malfunctioned during testing of Specimen 6; therefore, only data from one crackmeter, Crack 1, are presented. Figure 34 shows the moment versus crack width plot for Specimen 6.

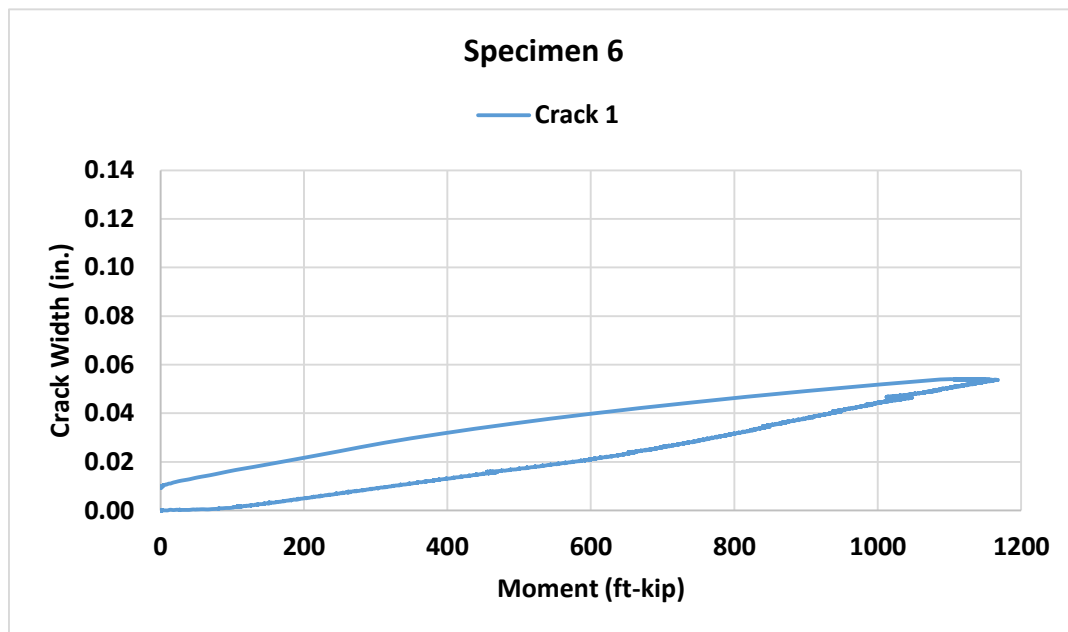


Figure 34. Moment versus crack width for Specimen 6

As shown in Figure 35, cracking of the joint on Specimen 6 appears to start with an applied moment of approximately 13 ft-k; whereas, cracking started almost immediately for the previous specimen.

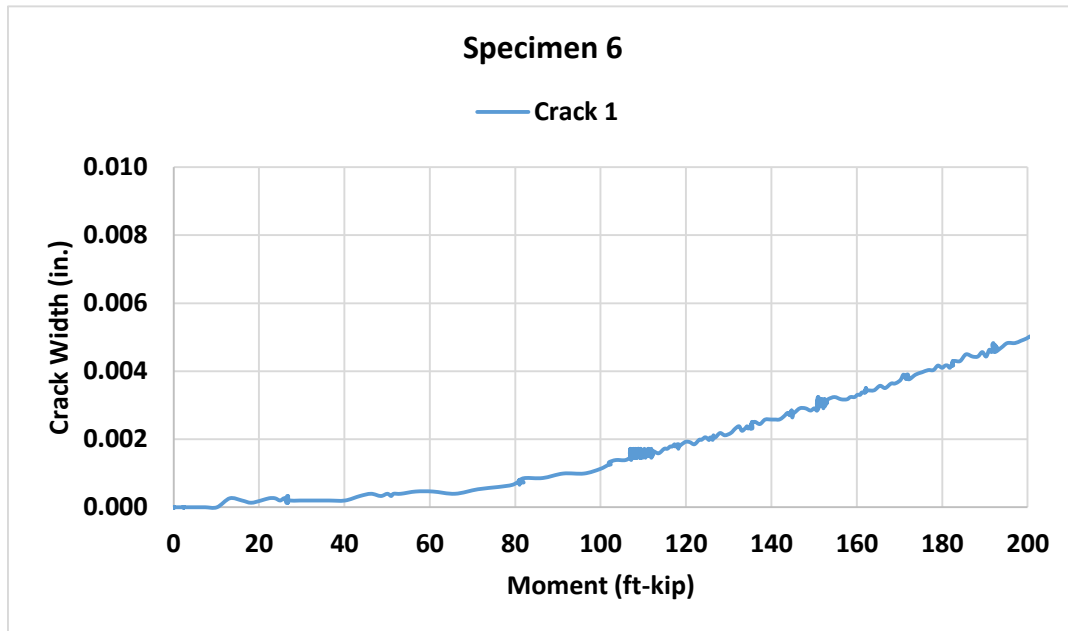


Figure 35. Initial crack width for Specimen 6

Figure 36 shows a typical crack during loading of one specimen (Specimen 3) with standard grout (left) and Specimen 6 using UHPC (right).



Specimen 3 (standard bedding grout)



Specimen 6 (UHPC bedding grout)

Figure 36. Crack width comparison during loading

Fatigue Bending Results

Specimen 7 was tested for fatigue up to approximately 1 million cycles. The fatigue test data indicated a well performing system with little to no creep in global deflection and/or crack width growth at the grouted interface throughout the duration of the 1 million plus cycles. In addition, upon conclusion of the testing, the global displacement and one working crackmeter returned to almost zero after unloading the system. Visibly, the cracks at the grouted joint were difficult to discern after removal of the load.

Figure 37 shows the global displacement versus cycles for the test.

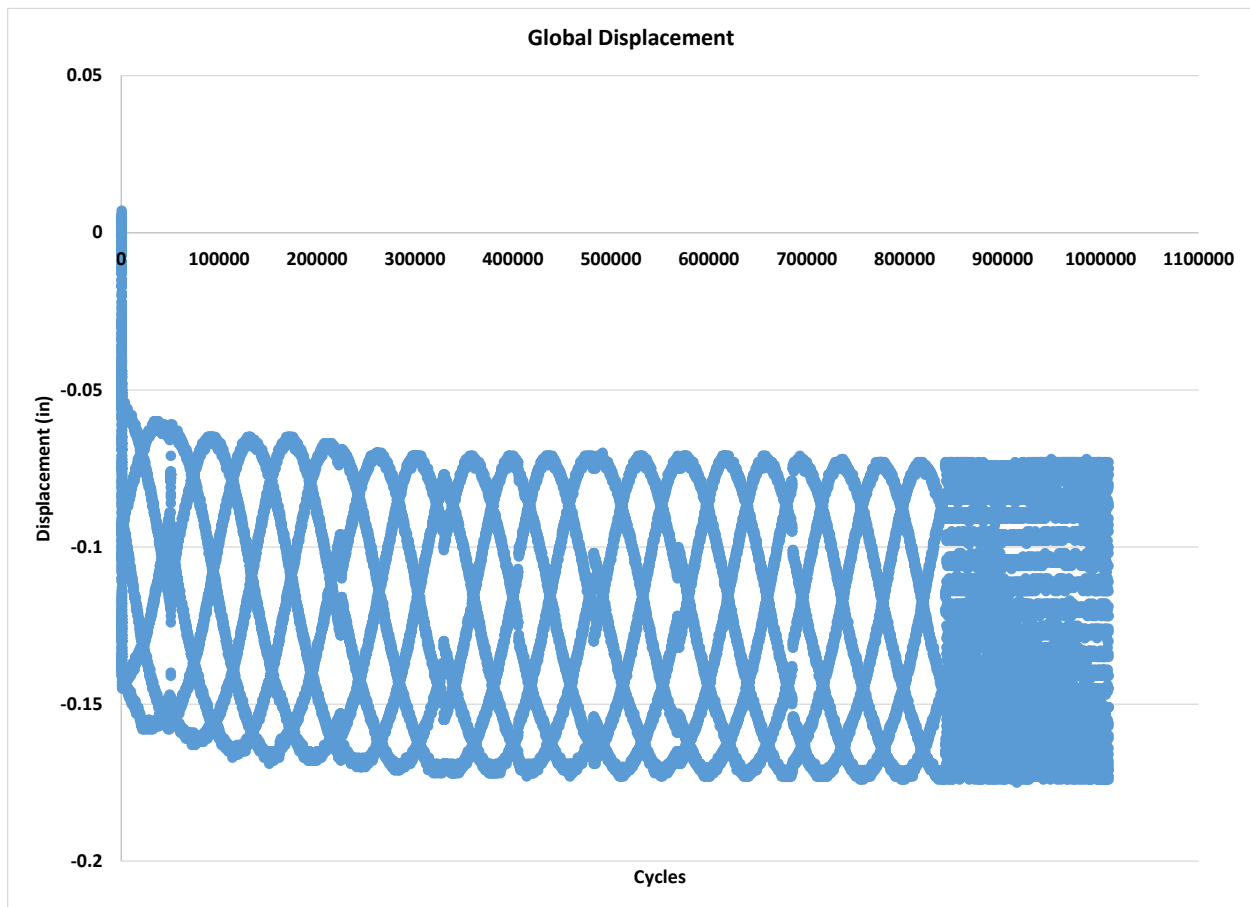


Figure 37. Specimen 7 fatigue test – global displacement

Figure 38 shows a typical crack width versus cycles plot.

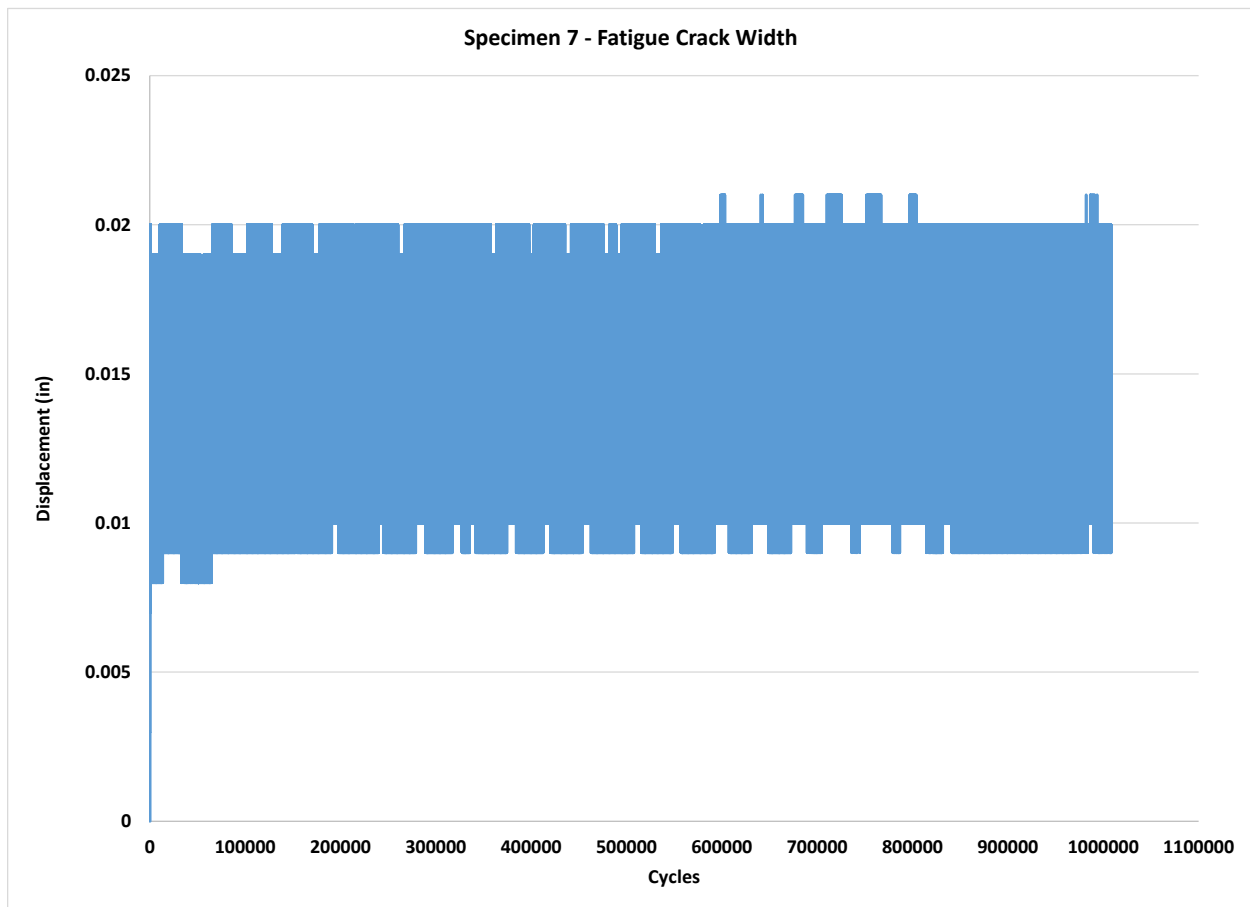


Figure 38. Specimen 7 fatigue test – crack width

Note that maximum crack width measured during the fatigue testing, approximately 0.02 in., was more than half of that measured during static testing, which would be expected given the reduced loading.

Chloride Penetration Results

All three small coupled specimens, with un-cracked grouted joints, were subjected to a 3% chloride bath for approximately six months and readings from the corrosion wires were taken periodically. Table 2 shows the results from the reading of the corrosion wires.

Table 2. Corrosion wire readings from small coupled specimens, millivolts (mV)

Reading Date	Specimen 1	Specimen 2	Specimen 3
June 2014	135	7	149
July 2014	210	9	38
August 2014	167	39	94
October 2014	172	8	30
December 2014	169	9	41

Readings from the corrosion wire presented in Table 2 are in millivolts; readings below 250 indicate a non-corroding strand, 300-400 millivolts suggest corrosion may be eminent, and readings over 400 indicate corrosion has started.

Throughout the monitoring of the specimens in the chloride solution, there were no readings suggesting that corrosion of the reinforcing steel was commencing. These results were somewhat expected because the grouted joints were uncracked, and the reinforcing steel in the specimens was epoxy coated, although the insides of the reinforcing steel couplers are not coated and this was one area of concern. At the conclusion of the chloride bath testing, each of the three specimens were broken apart at the grout bed for visual inspection. There was no evidence suggesting that moisture or chlorides had penetrated the grout bed.

SUMMARY OF RESULTS

Advancements and increased use of ABC often result in the use of newly developed, or modified, technologies and/or construction techniques that are sometimes untested in this new application. For designers and engineers to confidently make use of these technologies and construction methodologies, evaluation of their performance relative to design assumptions, short- and long-term durability, and other performance-based metrics is required in laboratory tests.

One particular technology that has been transferred and utilized in several ABC projects are grouted reinforcing steel couplers. One specific project in particular, the Keg Creek Bridge on US 6 in Iowa, utilized grouted reinforcing steel couplers to connect drilled shafts to prefabricated pier columns and then the pier columns to prefabricated pier caps. The use of this technology was one of the many critical elements that allowed the construction of the Keg Creek Bridge to be completed with less than two weeks of road closure.

Although their use has become more common in ABC projects, none of the testing of the grouted couplers was directly transferrable to these ABC applications and, as such, questions had been raised regarding their durability and performance in these real world applications. Following the Keg Creek Bridge project, the Iowa DOT initiated a project to evaluate the grouted reinforcing steel couplers using connection details similar to those used on the Keg Creek Bridge.

Previous research and testing on these types of couplers has largely focused on the direct tension strength of the coupled reinforcing steel connection. In the case of the Keg Creek Bridge, the grouted couplers were utilized in areas where the primary loading on them would be axial compression from dead and live loads, and bending due to thermal loads and live loads.

The scope of work for this project incorporated a laboratory evaluation of full-scale specimens to evaluate the structural performance of a connection detail utilizing grouted reinforcing steel couplers, and specifically the magnitude of the crack width that develops under load and how well the crack closes after removal of the load. Performance metrics included validation of design assumptions related to strength, but centered on the durability of the connection for both short and long-term performance.

Seven large specimens were cast utilizing two #14 epoxy-coated grouted reinforcing steel couplers, specifically Dayton Superior Sleeve-Lock couplers, per specimen and tested in a four-point bending configuration with the coupled reinforcing steel in the tension region of the specimen; six of the specimens were tested statically and the last specimen was tested in fatigue.

Specimens 1 through 3 were all load tested to a peak load of approximately 360 kips with no axial load applied to the specimens. Specimens 4 and 5 were then tested with axial loads of 54 kips and 115 kips, respectively, applied to simulate loading of the columns/connections in the

Keg Creek Bridge. Overall, static testing validated the design assumptions and provided good correlation to empirical calculations utilized during design of the specimens.

Specimens 1 through 5 were erected using the same grout for the grout bed as was used on the Keg Creek Bridge, W. R. Meadows 588-10k. Further evaluation of the data from the first five specimens indicated that the applied axial load on the specimens had a minimal effect on the performance of the grouted reinforcing steel coupled joints when loaded in bending. For both the case of a non-axially loaded and axially loaded specimen, the initiation of the crack at the grout interface was almost immediately upon loading.

The last specimen tested in static bending was Specimen 6. This specimen was fabricated using UHPC as the bedding grout and an axial load of 54 kips to allow for comparison with the previously tested Specimen 4. Like the first five specimens, Specimen 6 was loaded to approximately 360 kips and the grout joint monitored.

Based on test data, initiation of the crack at the grout interface for Specimen 6 using the UHPC occurred at an applied moment of approximately 13 ft-k. This suggests that use of UHPC for the bedding grout in this application would slightly delay the initiation of cracking of the joint. However, there was no improvement in the degree to which the crack closed upon unloading or the magnitude of the crack width during loading when compared to Specimens 1 through 5.

The last specimen, Specimen 7, was tested in fatigue to approximately 1 million cycles using a point load of 106 kips. This was the point load calculated to produce the 18 ksi stress in the coupled #14 bars specified by the AASHTO LRFD Specification (AASHTO 2010). The fatigue test data indicated a maximum global displacement of approximately 0.18 in., which was consistent throughout the duration of the testing. Likewise, the crack width at the grouted interface remained relatively constant during the 1 million cycles and never exceeded 0.02 in.

Three additional small specimens were cast, each with one #14 grouted coupler cast into an 8 in. diameter sonotube to provide a minimum of 2 in. of clear cover around the circumference of the coupler. Another 8 in. diameter cylinder with a protruding #14 bar was then grouted to the section with the coupler. The reinforcing steel in these three specimens were outfitted with corrosion wire and submerged in a 3 percent chlorine bath to just above the grouted joint. The specimens were allowed to soak for approximately 6 months with periodic readings taken on the corrosion wire. Because the grouted joints were uncracked, and the reinforcing steel was epoxy coated, no evidence of corrosion was seen during the testing of these specimens.

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